CLIC DRIVE BEAM FREQUENCY MULTIPLICATION SYSTEM DESIGN

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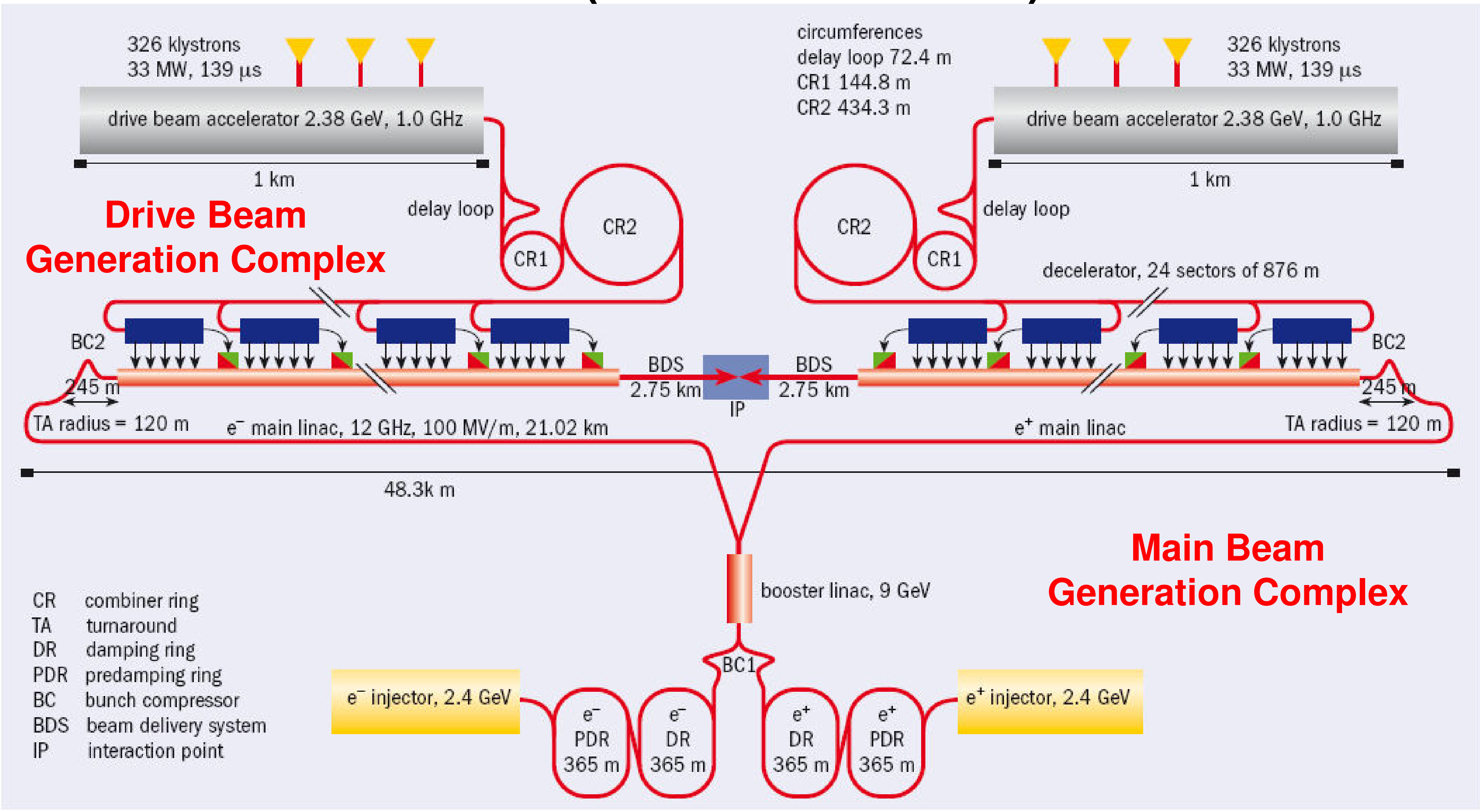
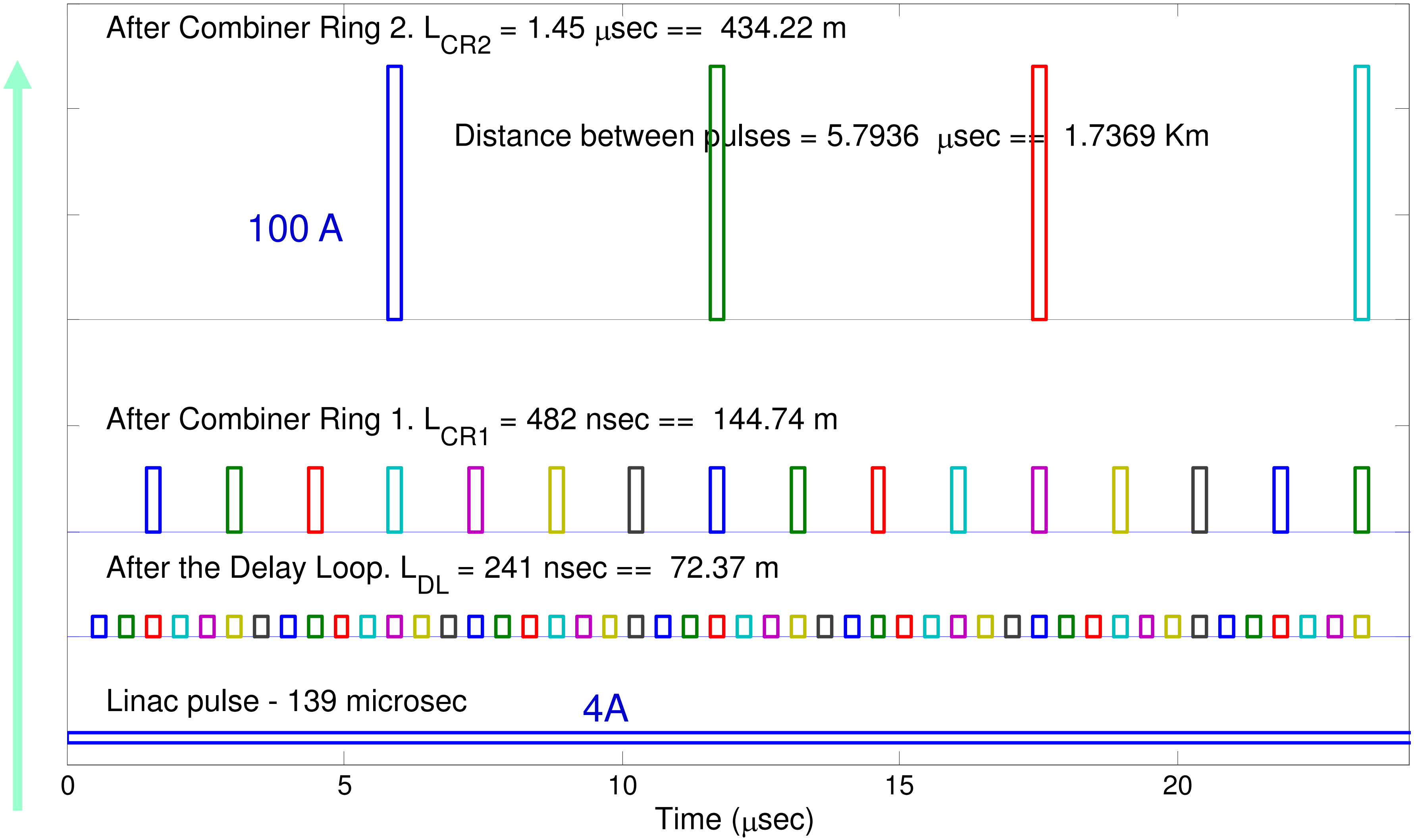
CLIC Layout 3 TeV
(not to scale)



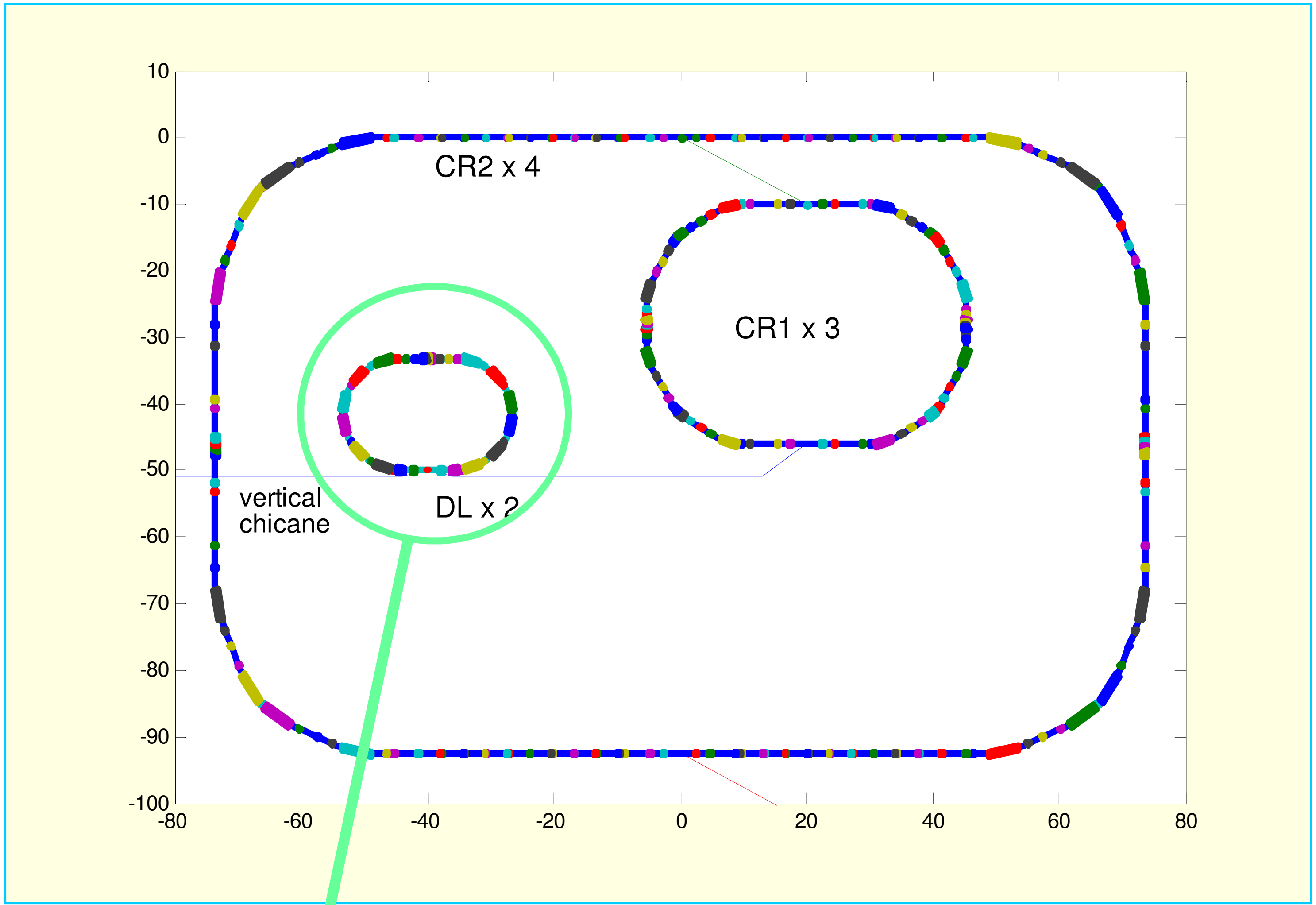
Beam temporal structure along the frequency multiplication system



E=2.37 GeV,
Energy spread < 1%,
Bunch charge = 8.4 nC

Emittance ~ 100 μm rad
Bunch length 2mm
Final bunch separation = 2.5 cm

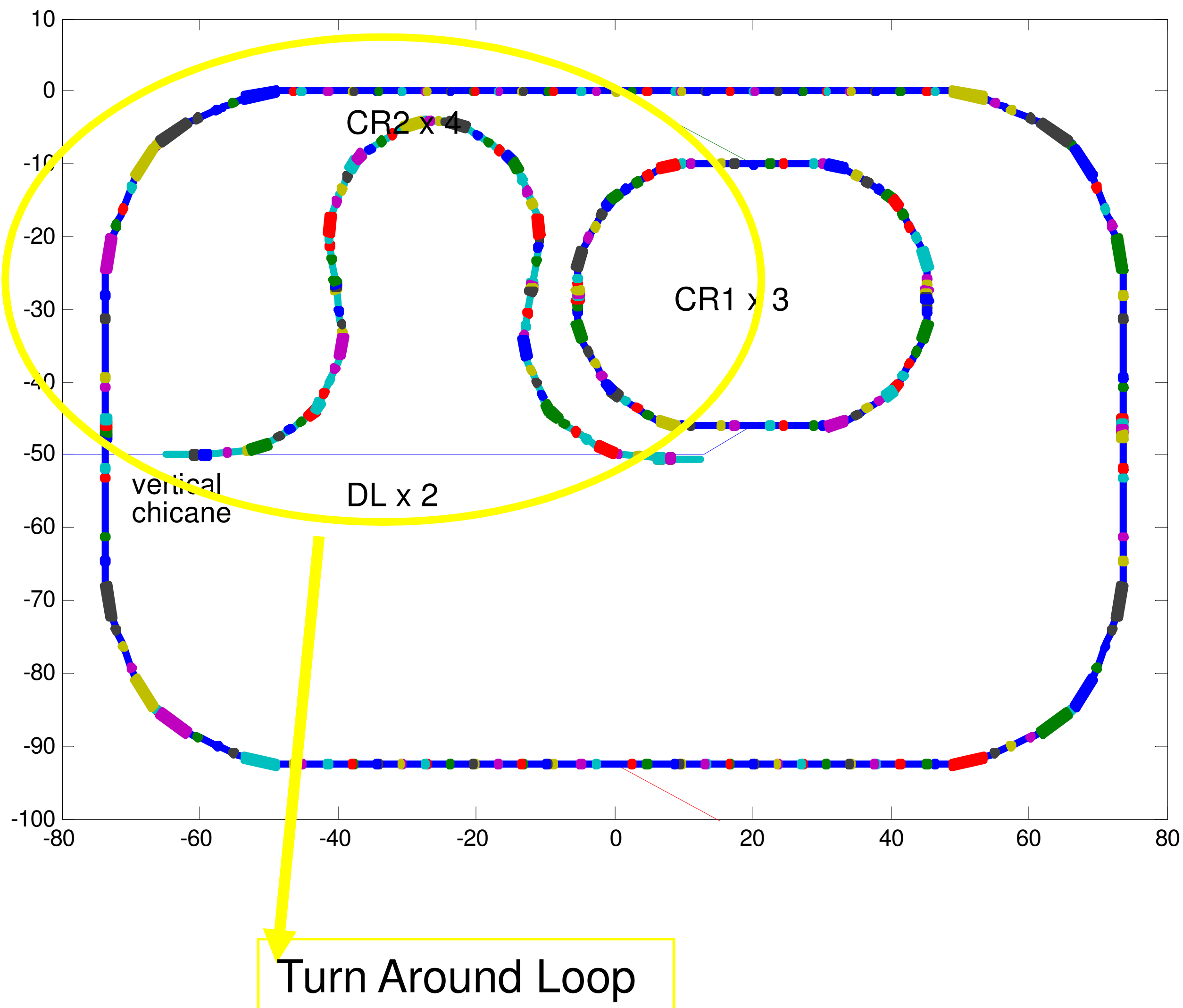
FMS layout



Delay Loop as in CTF3

May 09

FMS layout



June 09

Main parameters of the rings

Parameter		**DL**	**TA**	**CR1**	**CR2**
L	m	**73.05**	**146 + 73**	**146.09**	**438.28**
Combination factor		**2**	**2**	**3**	**4**
RF deflector frequency	GHz	**1.5**	**1.5**	**2.**	**3.**
N of dipoles		**12**	**12**	**12**	**16**
ρ	m	**4.7**	**4.7**	**4.7**	**12**
B	T	**1.7**	**1.7**	**1.7**	**0.7**
N of quadrupoles / families		**18 / 9**	**44/17**	**48 / 9**	**64 + fodo quads**
$l_q * dB/dx$ max	T	**10**	**11**	**6**	**6**

DL against TA

DELAY LOOP	TURN AROUND
L = 73 m	L = 73 * 2 + 73 m
Total bending angle = 2π	Total bending angle > 10%
Low number of elements	High number of elements
1 rf deflector	2 rf deflectors
High element density	Low element density
Higher T566 (-55m, sext off)	Lower T566 (-35, sext off)
	Better tunability

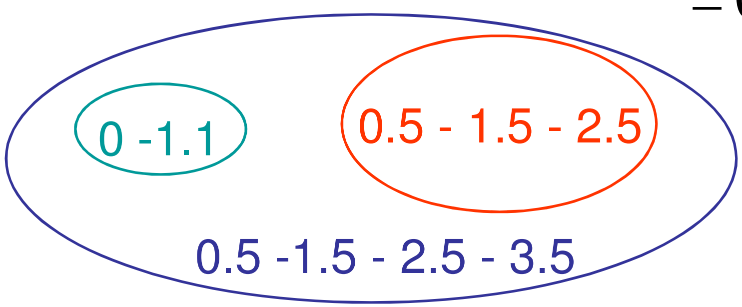
Energy loss per turn (Incoherent Synchrotron Radiation)

$$U_0(keV) = 88.46\frac{E(GeV)^4}{\rho(m)} =$$

$$= 0.6\,MeV \qquad \rho = 4.7m$$

$$= 0.235\,MeV \qquad \rho = 12m$$ @CR2

Number of turns

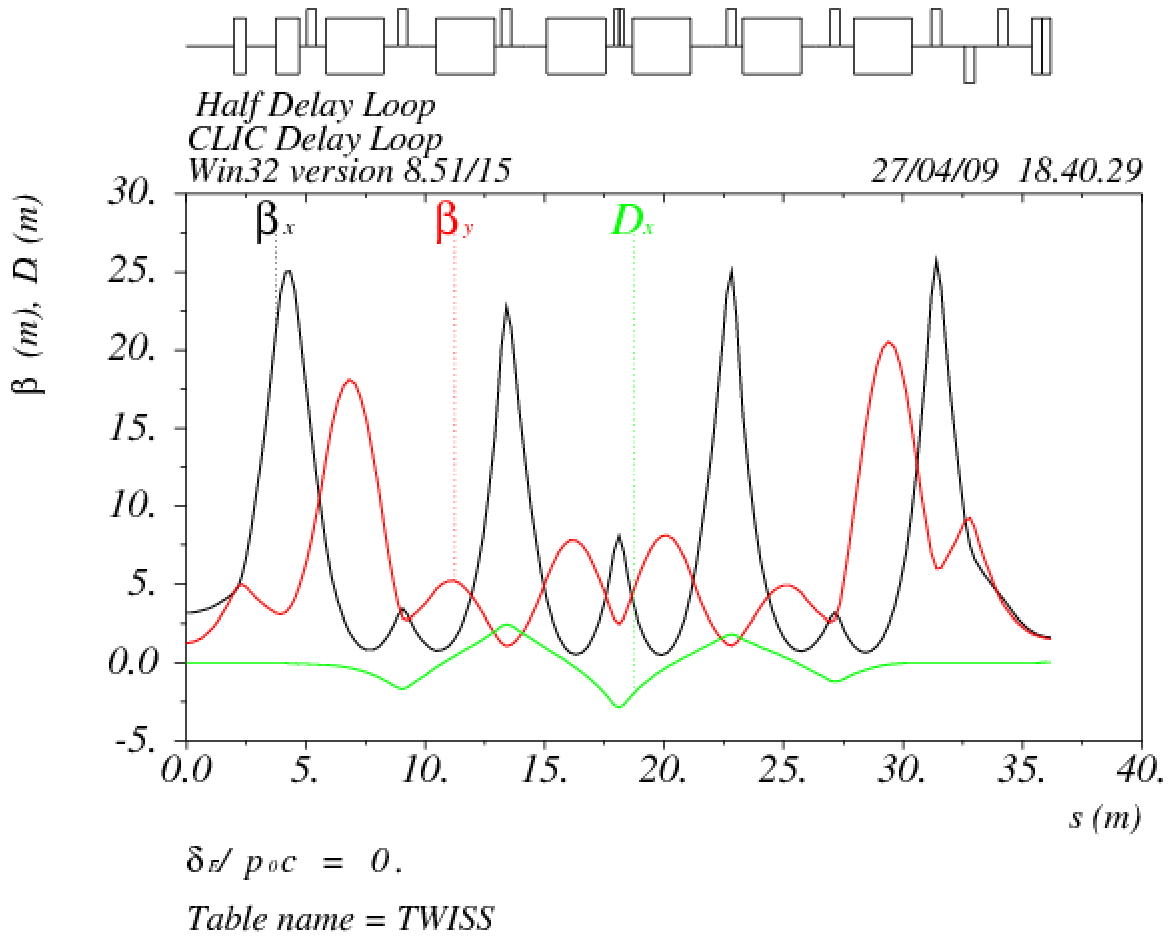


From 1 turn to 7.1 turns: energy loss from 0.42 to 3 MeV

↓

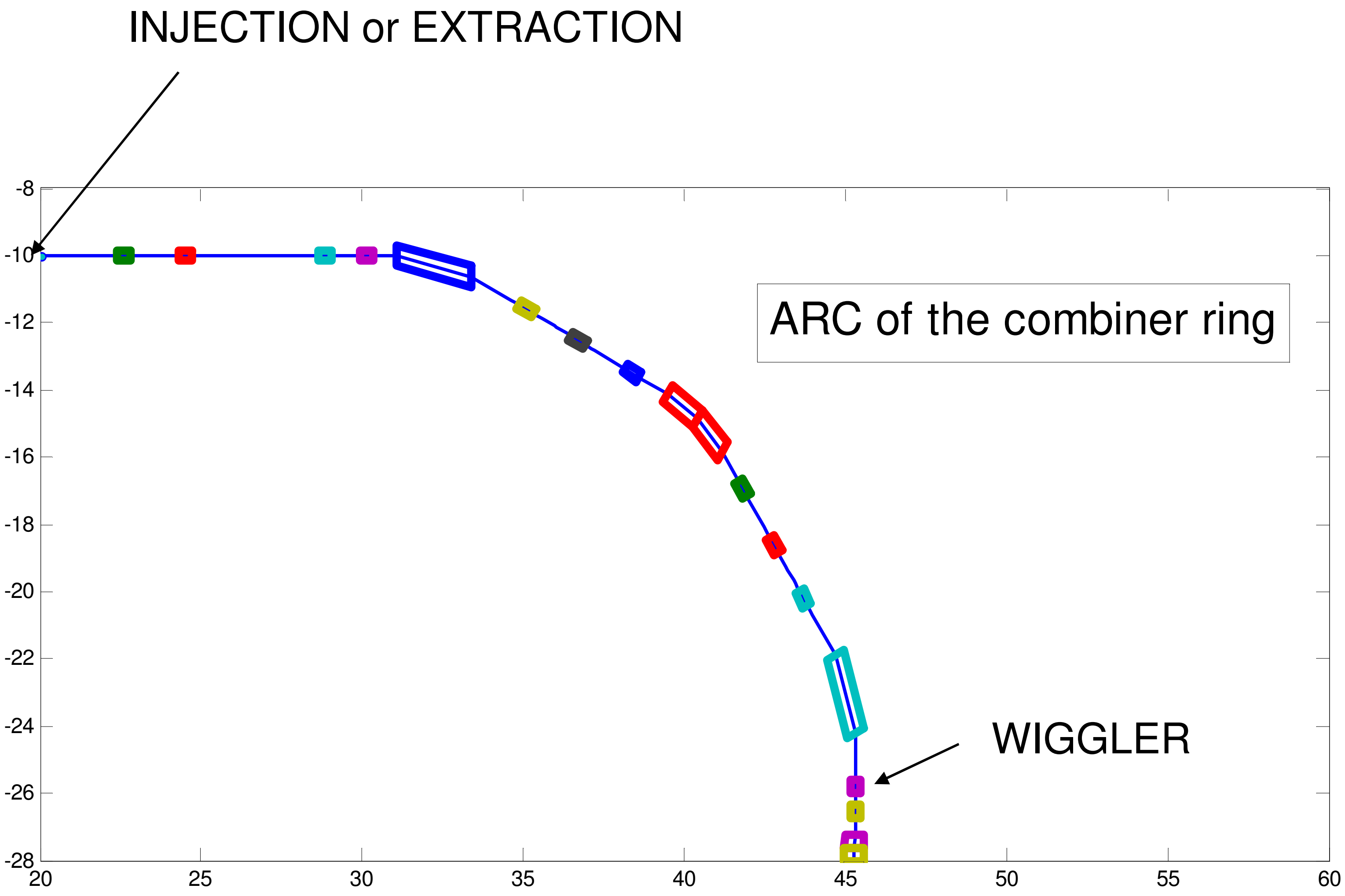
Spread between the minimum and maximum lost: ΔE/E ~ 0.1 %

Delay loop – full of dipoles – $\rho = 4.7$ m



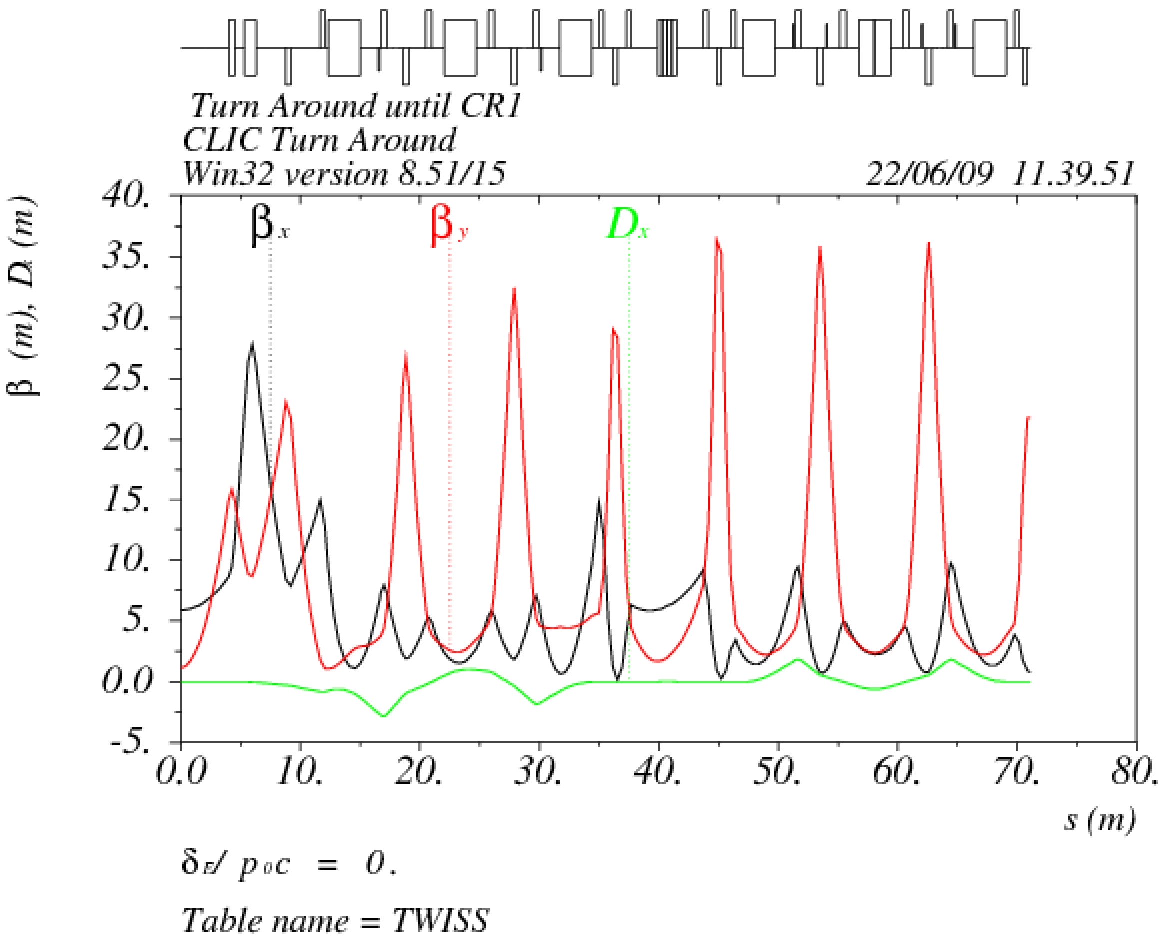
Field index in dipoles

CLIC CR1 and TA– similar to CTF3 CR



In TurnAround Loop dipoles bend 33° instead of 30°

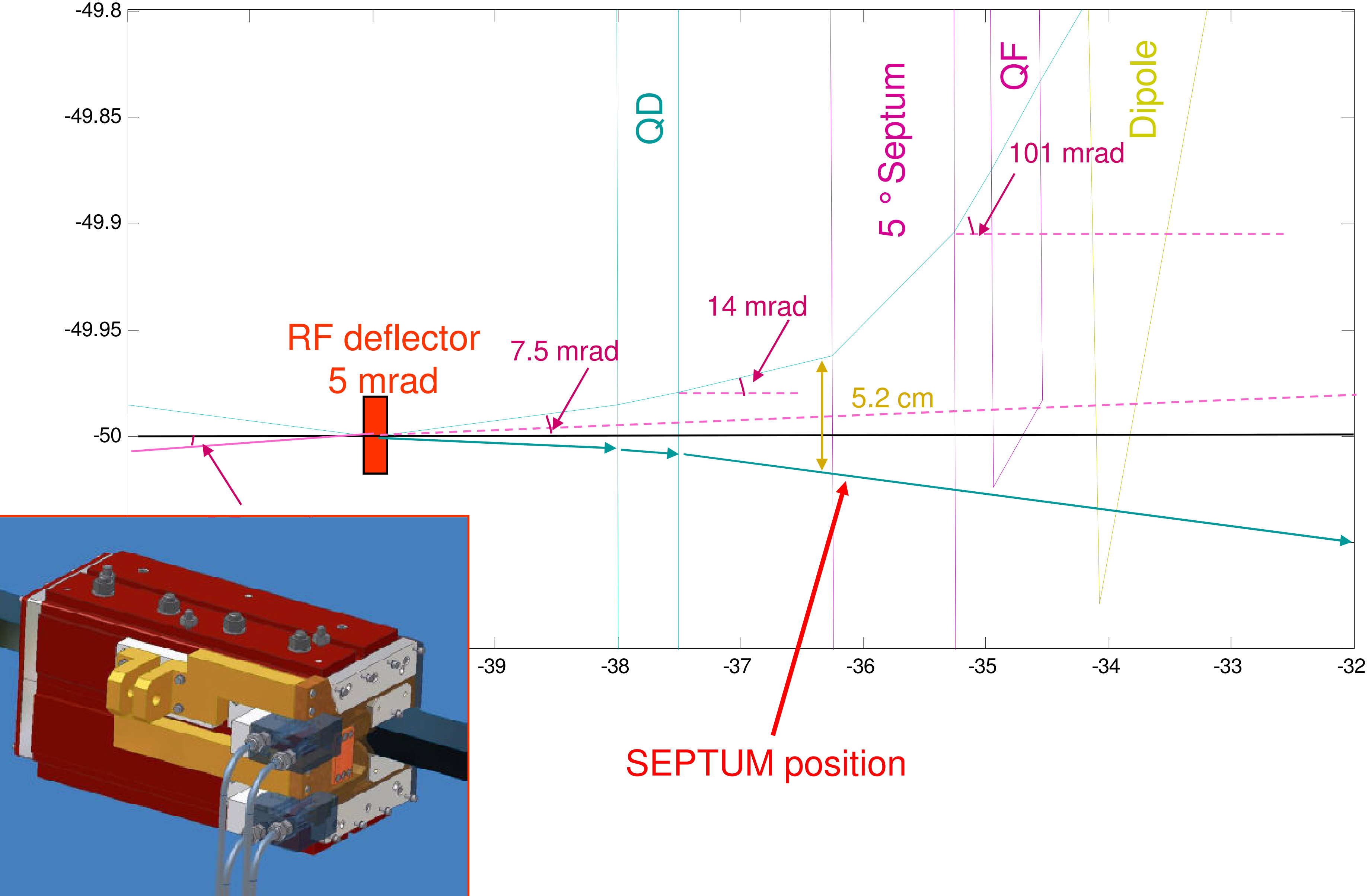
Turn Around Loop – same isochronous arc of CR



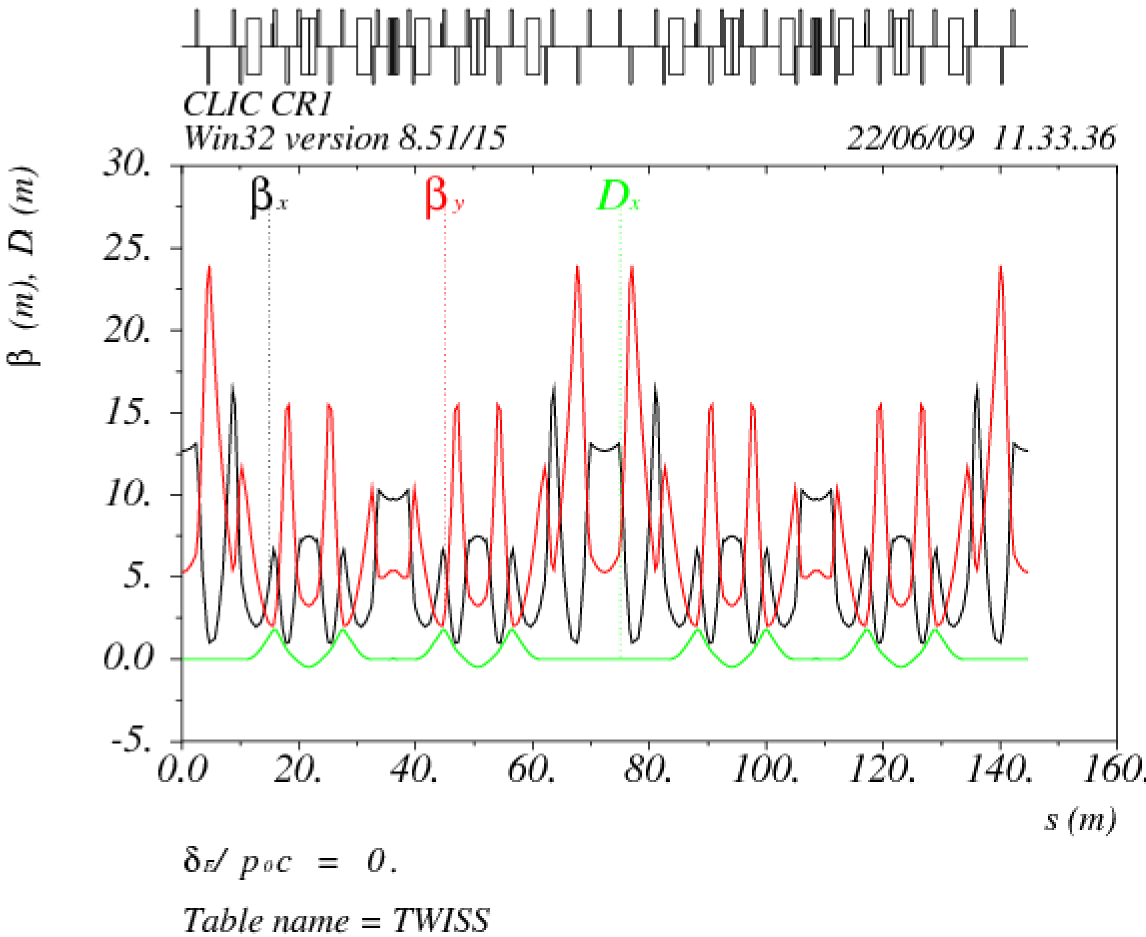
ADDING a Dquad between the rf deflector and the septum

The odd and even bunches are separated and vertically focused on the septum position

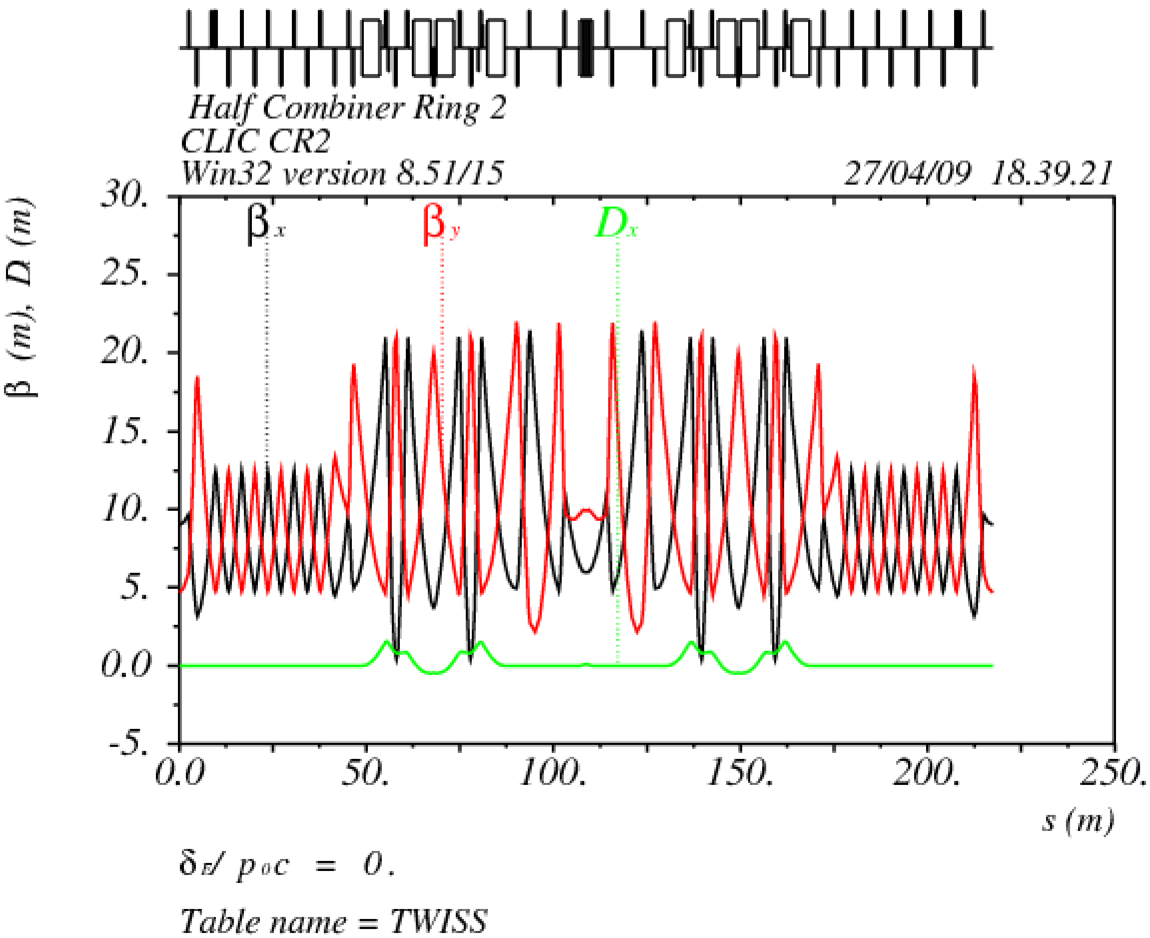
DL injection - extraction region



1 ° combiner ring



2° combiner ring



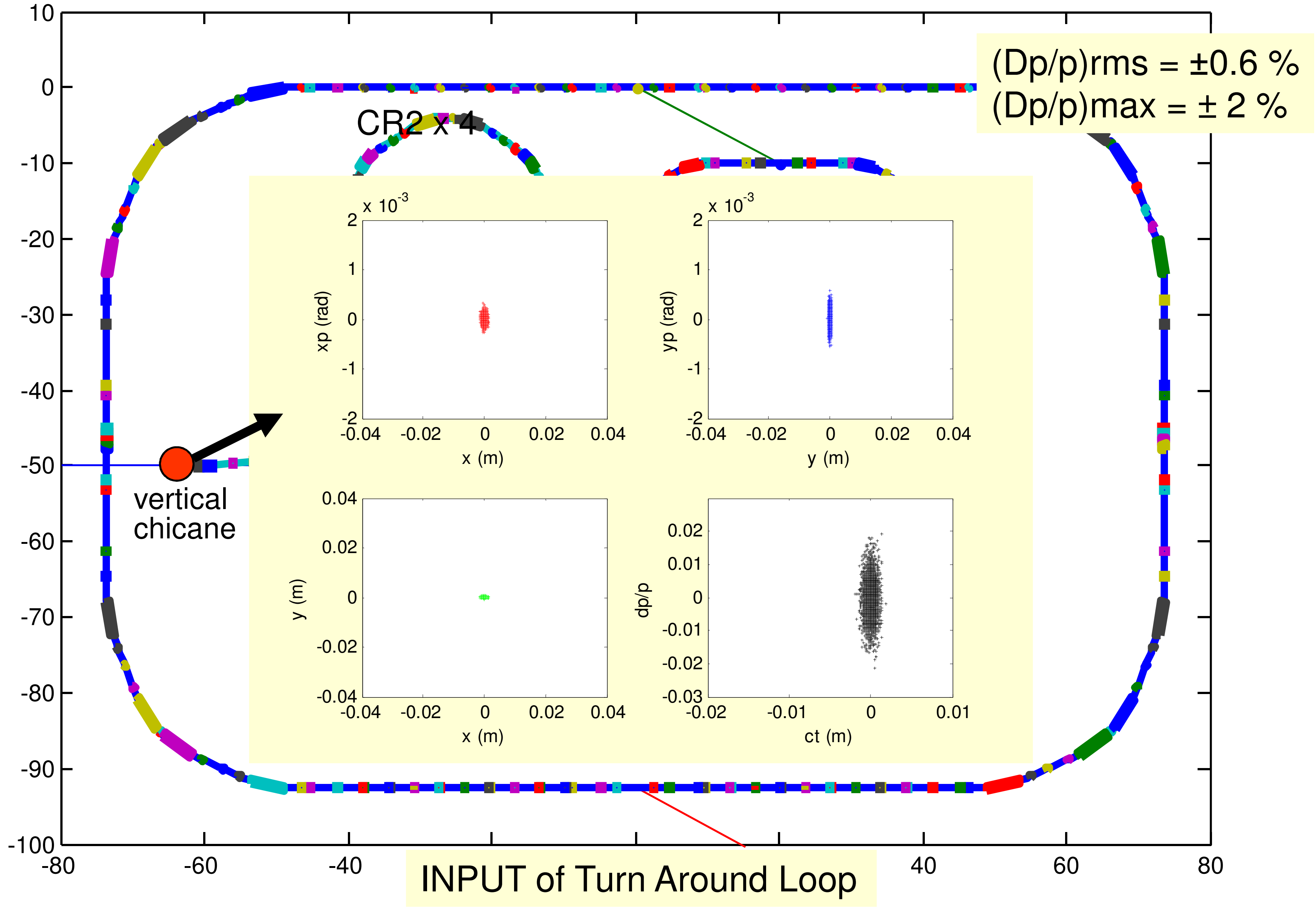
Tracking 6d particle distribution along fms

Optimisation of 2° order chromaticity terms – work in progress

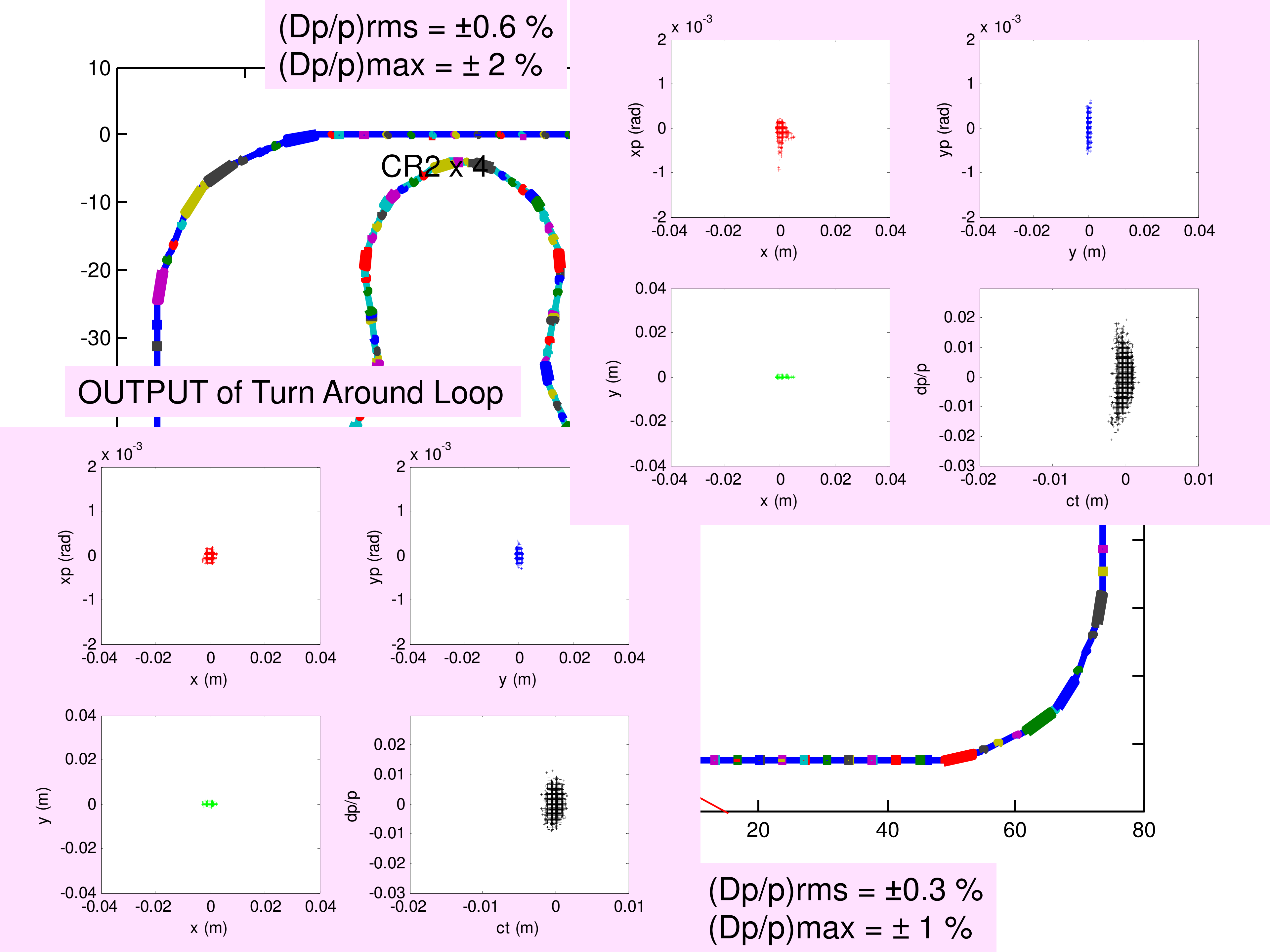
- Beam energy spread is the parameter mostly influencing the three phase spaces.
- Correcting the 2° term isochronicity by sextupoles can be harmful for the transverse planes.
- Up to ± 1% of energy spread 3 emittances are easily preserved.
- Particles with higher energy deviations can be lost transversely when sextupoles are not carefully optimised

Dp/p = 1% -> 3.5 mm

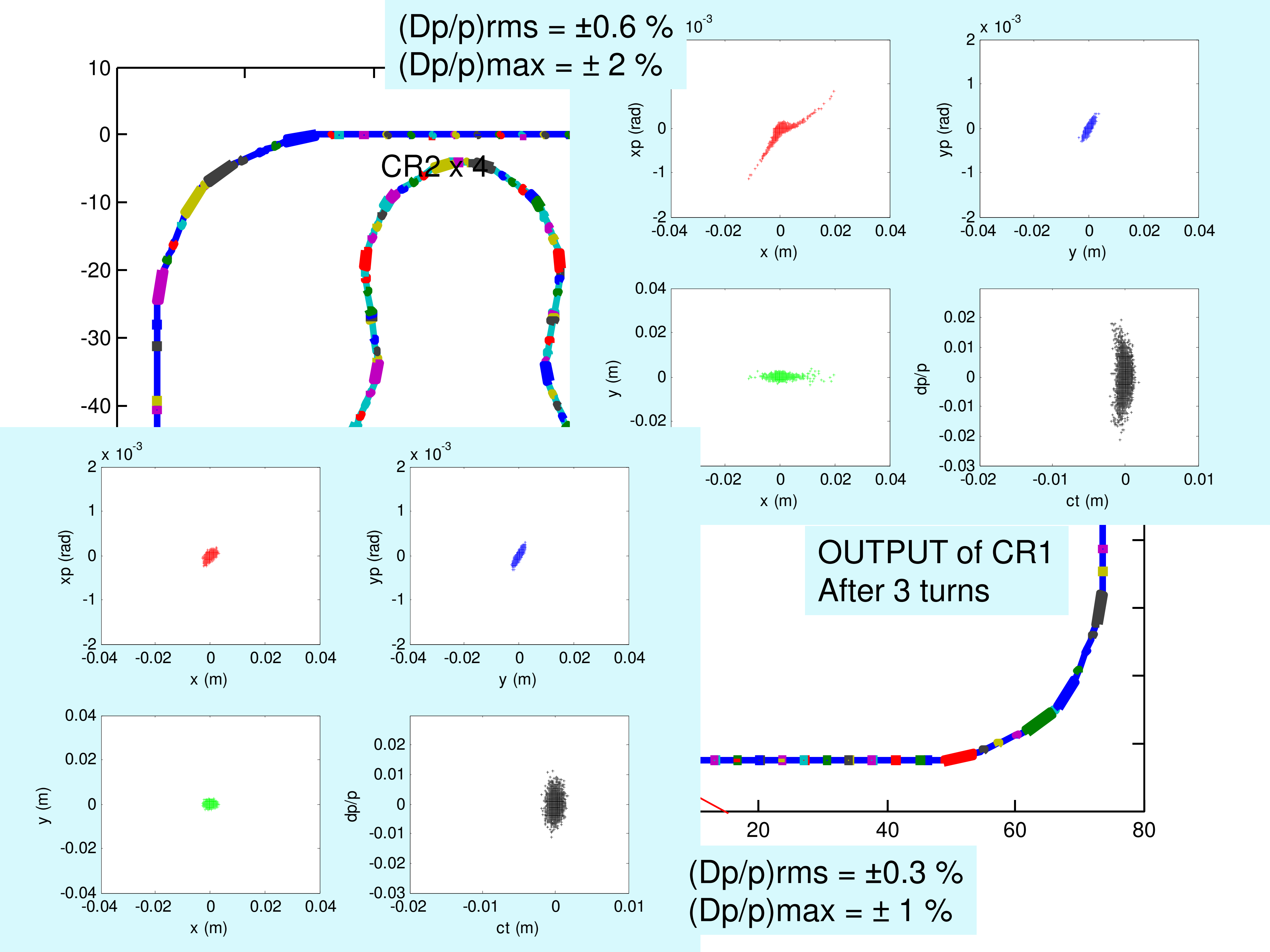
	TA	CR1	CR2
T566 sext off	-34.6	-19.2	-13.4
T566 sext on	-4.4	-0.6	0.2
T166 sext off	-42.	-4.5	22.6
T166 sext on	5.8	-0.5	-48.

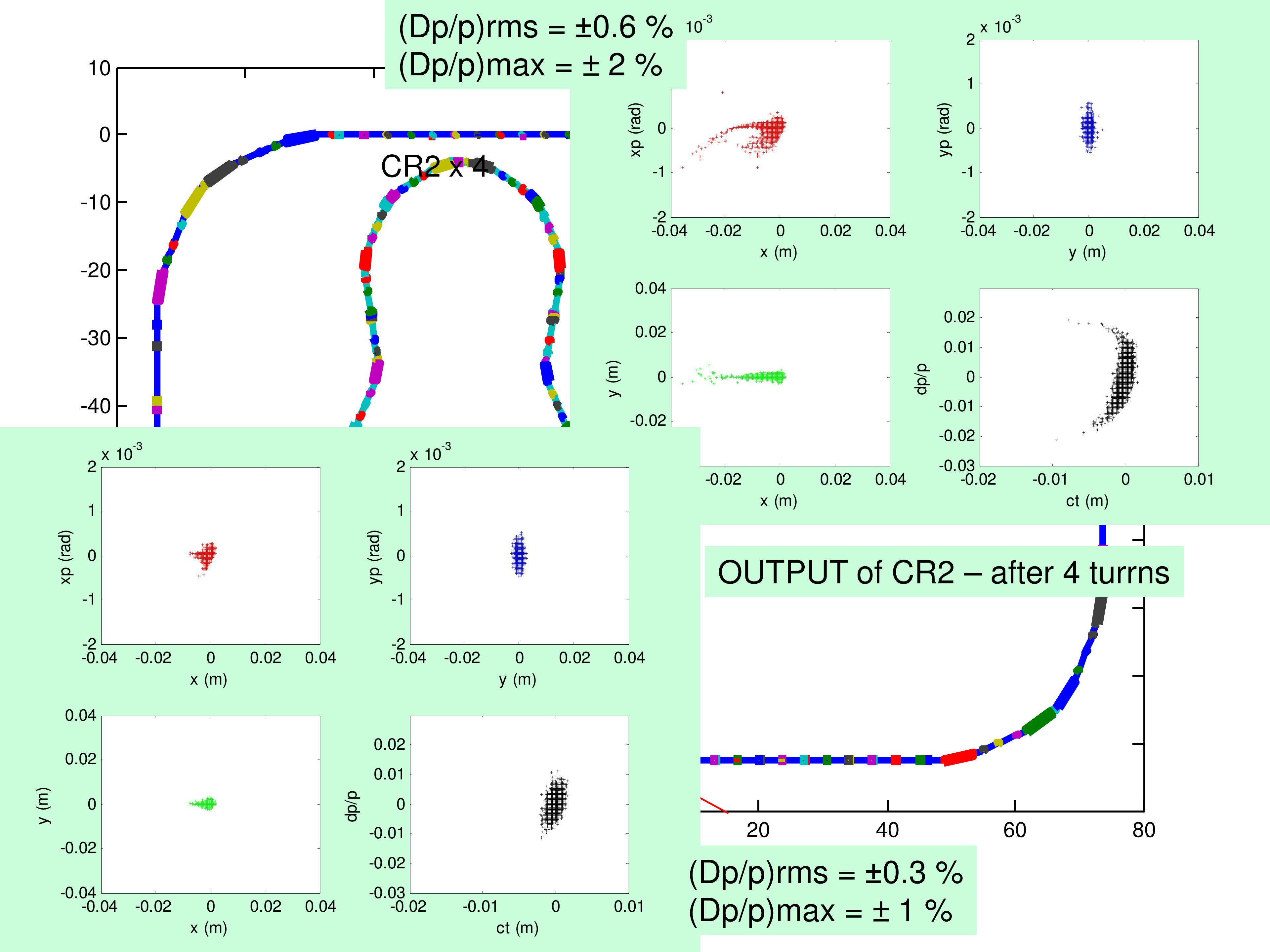


(Dp/p)rms = ±0.6 %
(Dp/p)max = ± 2 %
CR2 x 4
vertical chicane
INPUT of Turn Around Loop
x 10^-3
xp (rad)
x (m)
yp (rad)
y (m)
dp/p
ct (m)



(Dp/p)rms = ±0.6 %
(Dp/p)max = ± 2 %
CR2 x 4
OUTPUT of Turn Around Loop
xp (rad)
x (m)
yp (rad)
y (m)
y (m)
x (m)
dp/p
ct (m)
x 10-3
(Dp/p)rms = ±0.3 %
(Dp/p)max = ± 1 %


(Dp/p)rms = ±0.6 %
(Dp/p)max = ± 2 %
CR2 x 4
OUTPUT of CR1
After 3 turns
(Dp/p)rms = ±0.3 %
(Dp/p)max = ± 1 %
xp (rad)
x (m)
yp (rad)
y (m)
dp/p
ct (m)



(Dp/p)rms = ±0.6 %
(Dp/p)max = ± 2 %
CR2 x 4
OUTPUT of CR2 – after 4 turrns
(Dp/p)rms = ±0.3 %
(Dp/p)max = ± 1 %
xp (rad)
x (m)
yp (rad)
y (m)
dp/p
ct (m)
x 10^-3

MAD X

Correction for CR1 : one sextupole family

T566 = 0

Q'x = -9.8 sext off, and -2.1 sext on

Q'y = -10.4 sext off, and -13.6 sext on

$\Delta\beta/\beta < 0.22$ for 2% of δp.

Tracking particles of amplitudes $A_{x,y}$ = 1,2,3 $\sigma_{x;y}$ evenly spaced in phase and covering the momentum range $\pm$ 2% over three turns:

- no significative deformation of the vertical phase-space
- the horizontal phase-space is preserved up to $\delta p = \pm 1.2$ %

- Qualitatively and quantitatively same results of Madx, but with different sextupole strengths

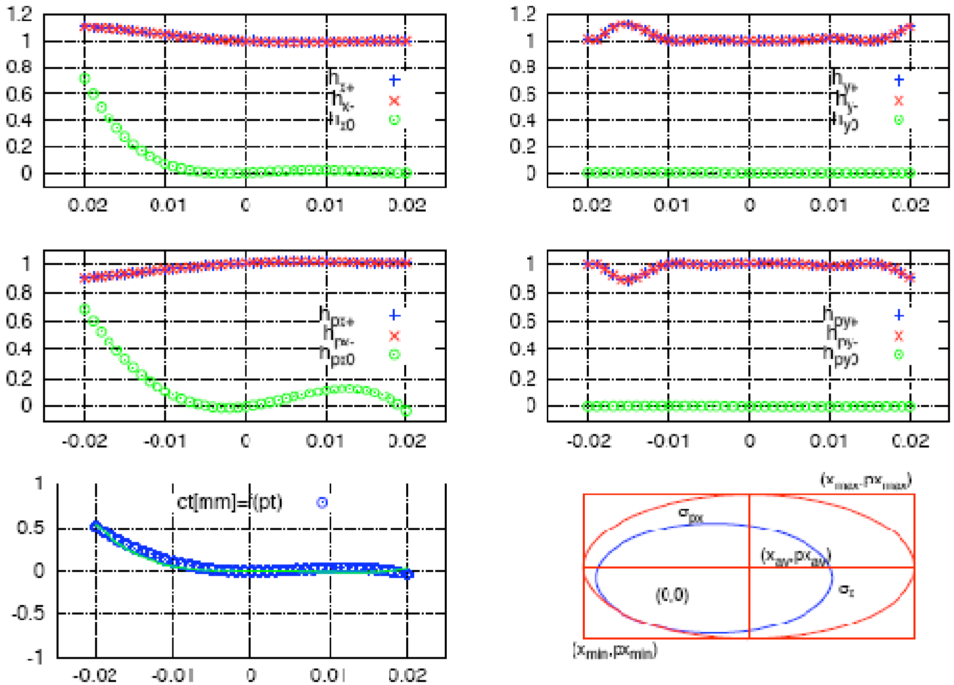


Figure 2: The results of thee turns tracking through CR1. Four upper pictures : the functions $h(\delta_p)$ defined in the text for the four canonical transverse phase-space variables x, px, y, py. Down right: the extrema of the 1σ deformed phase-space (red) at δ_p observed in the tracking data which are used to construct the h functions, compared to the nominal (blue) phase-space ellipse (σ_x, σ_{px}). Down-left : the residual ct error with δ_p . The red-curve is an eye-fit mixing of polynom with 3^{rd} and 4^{th} terms.

$$h_{x+}(\delta_p) = [x_{\max}(\delta_p) - x_{av}(\delta_p)] / \sigma_{\beta,x}$$

$$h_{x-}(\delta_p) = [x_{av}(\delta_p) - x_{\min v}(\delta_p)] / \sigma_{\beta,x}$$

$$h_{x0}(\delta_p) = x_{av}(\delta_p) / \sigma_{\beta,x}$$

MadX – mad8

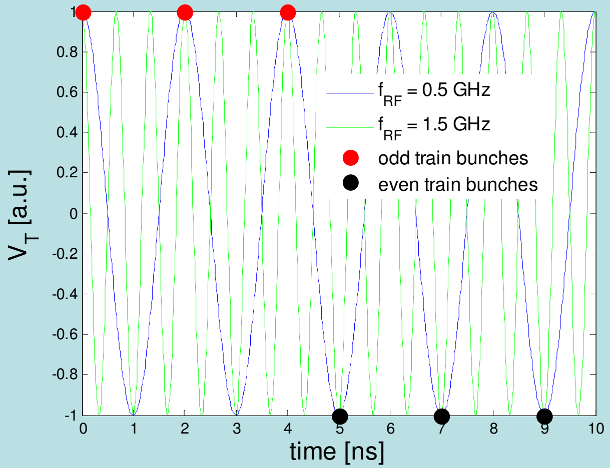
- Different values for chromaticity evaluation
- 2° order longitudinal correction slightly different

Use ctf3 combiner ring as benchmark:

Apply sextupole corrections for bunch length and chromaticity optimisation
Measurements of bunch length and of beam emittances in TL2

RF deflectors

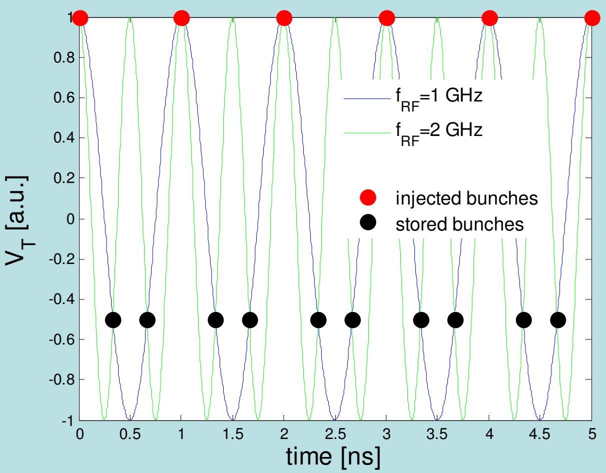
Deflector Frequencies



Delay Loop:

$f = f_{linac}/2\ (2n+1),\ \ n=0,1,2,\ldots$

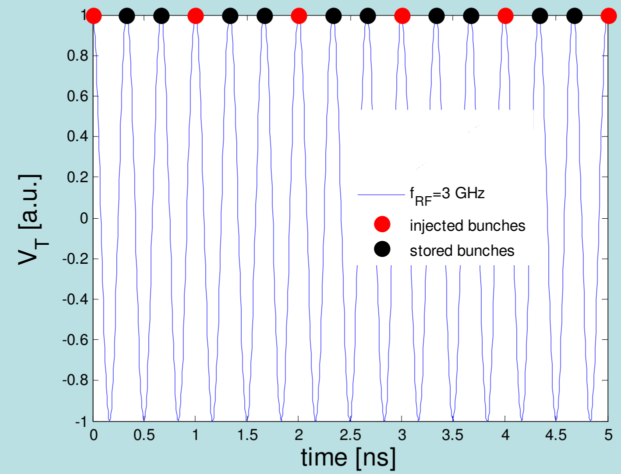
f = 0.5 GHz, 1.5 GHz, 2.5 GHz,…



Combiner Ring 1:
(recombination factor m = 3)

$f = nf_{bunch},\ \ n=1,2,4,5,\ldots$
(but $n \neq m$ and its multiple integers)

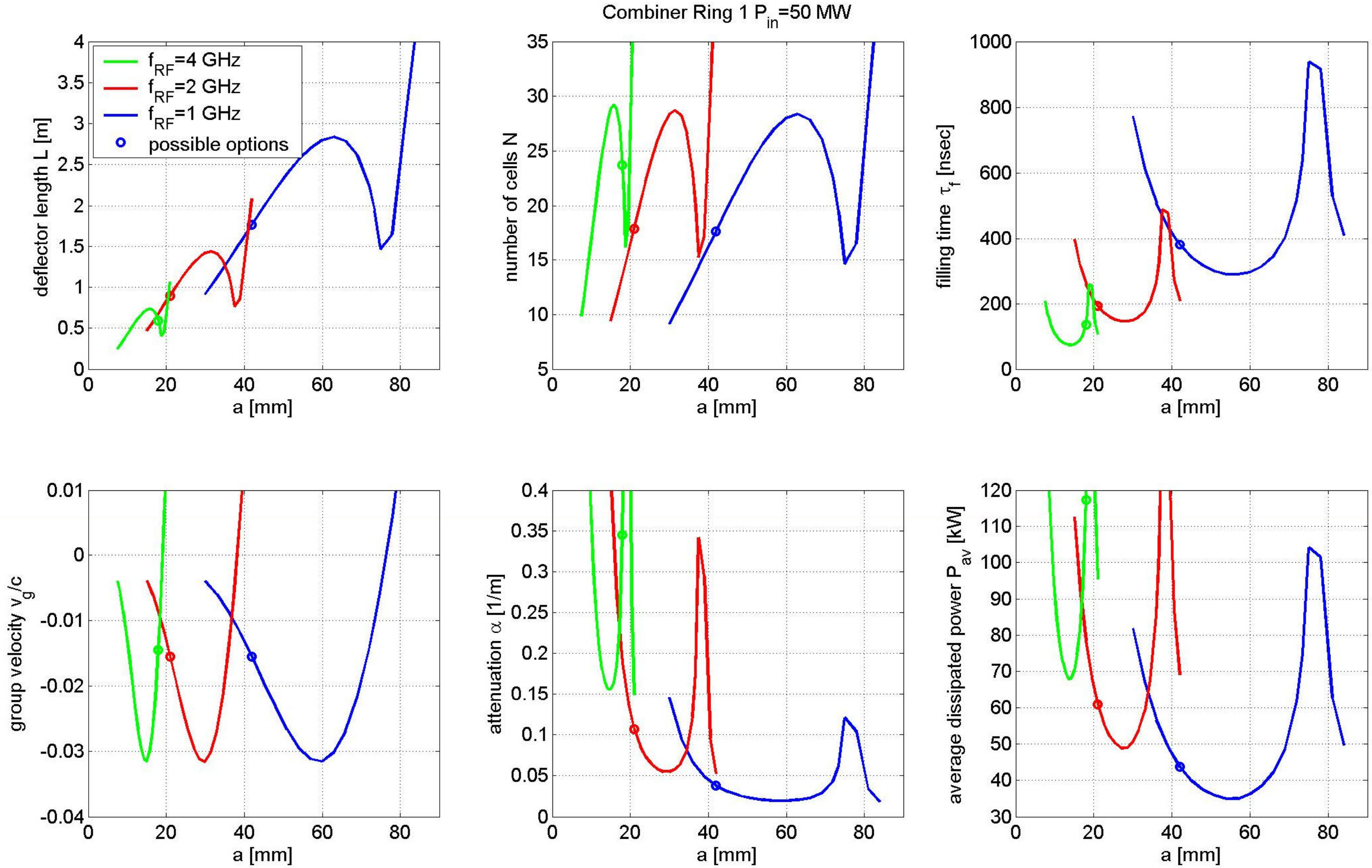
f = 1 GHz, 2 GHz, 4 GHz,…



Same rule for CR2 (recombination factor m = 4):

f = 3 GHz, 6 GHz,…

COMB RING 1



f [GHz]	a (mm)	L (m)	N	τ_f [ns]	v_g/c	α [1/m]	P_{av} [kW]	Z [$V^2/m^2/W$]
1	42	1.7	17	379	-0.016	0.04	44	9.6e5
2	21	0.9	18	192	-0.016	0.1	60	3.7e6
4	18	0.6	24	136	-0.014	0.34	117	9.8e6

DEFLECTING FIELD EXCITED BY THE BEAM IN RF DEFLECTORS (1/2)

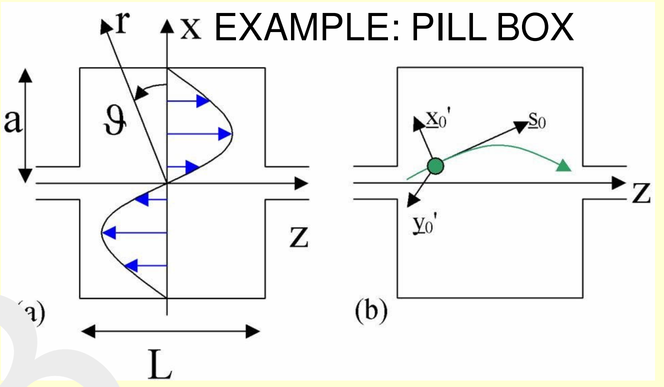
Unwanted deflecting field can be ***excited by the beam if the pass off-axis*** into the deflectors both in the horizontal than in the vertical plane.

This is due to the fact that the ***deflecting field has longitudinal electric field*** off-axis.

$$\underline{E}_D = \begin{cases} E_{Dz} = E_0 J_1(p_{11} x/a) \\ E_{Dx} = E_{Dy} = 0 \end{cases}$$

$$\underline{B}_D = \begin{cases} B_{Dz} = B_{Dx} = 0 \\ B_{Dy} = -jAE_0 J_1^{'}(p_{11} x/a) \end{cases}$$

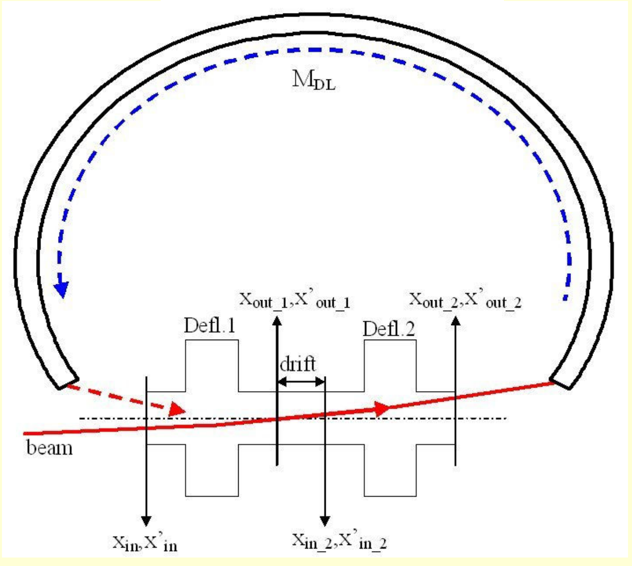
EXAMPLE: PILL BOX



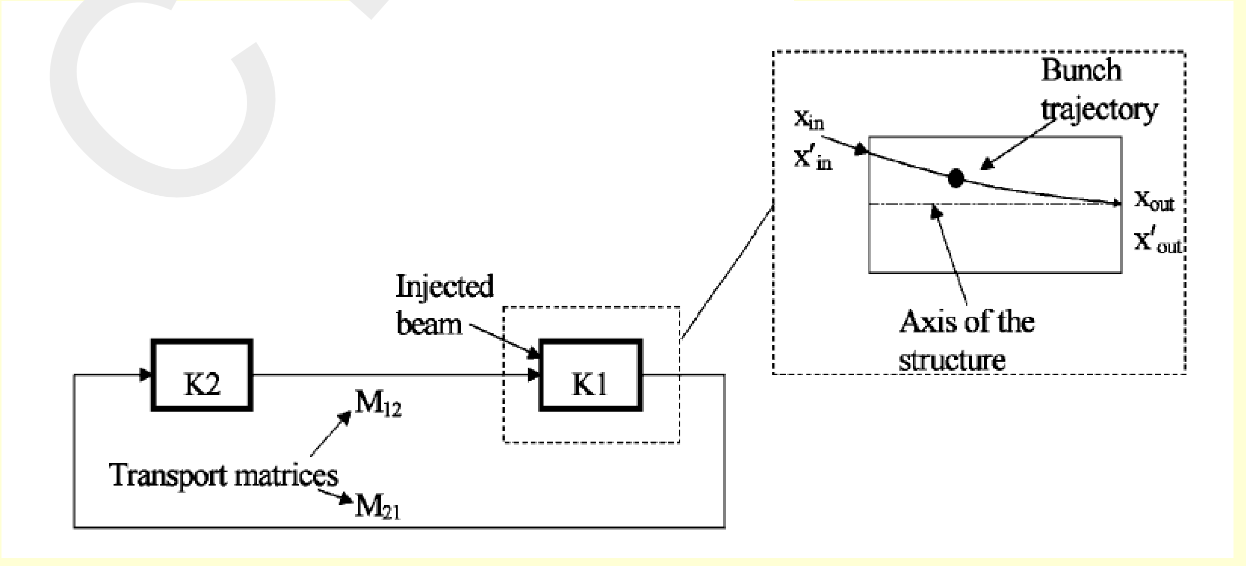
This happens, in the ***horizontal*** plane, even in the case of perfect injection and both in the DL than in the CR RF deflectors.

In the ***vertical plane there is beam loading only in case of a non-perfect steering*** of the orbit inside the structure.

DELAY LOOP

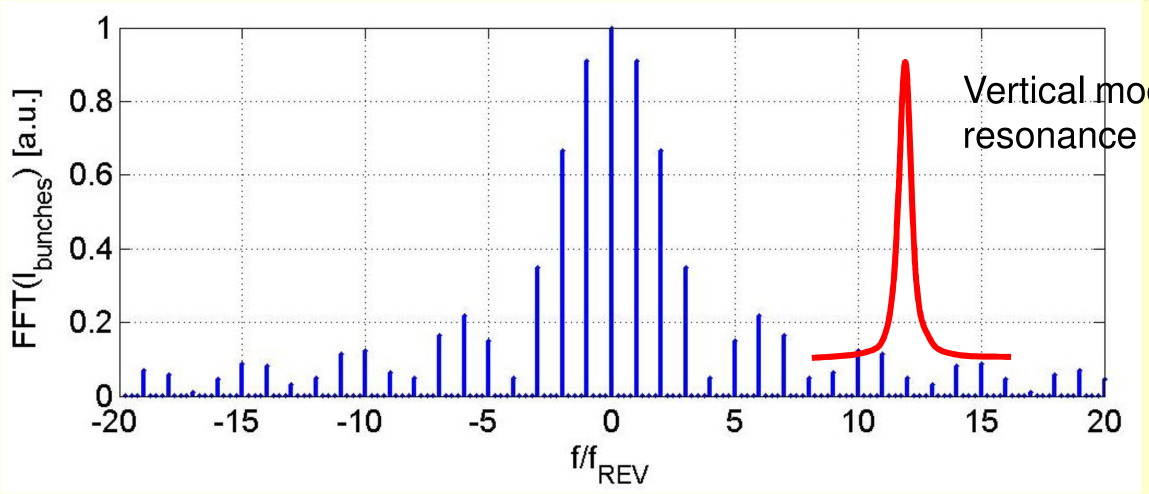


COMBINER RING



WAKEFIELD INDUCED BY THE VERTICAL MODES (3/3)

Spectrum of a 200 bunches in the combiner ring in 4 turns (f_{REV}≅3.56 MHz)



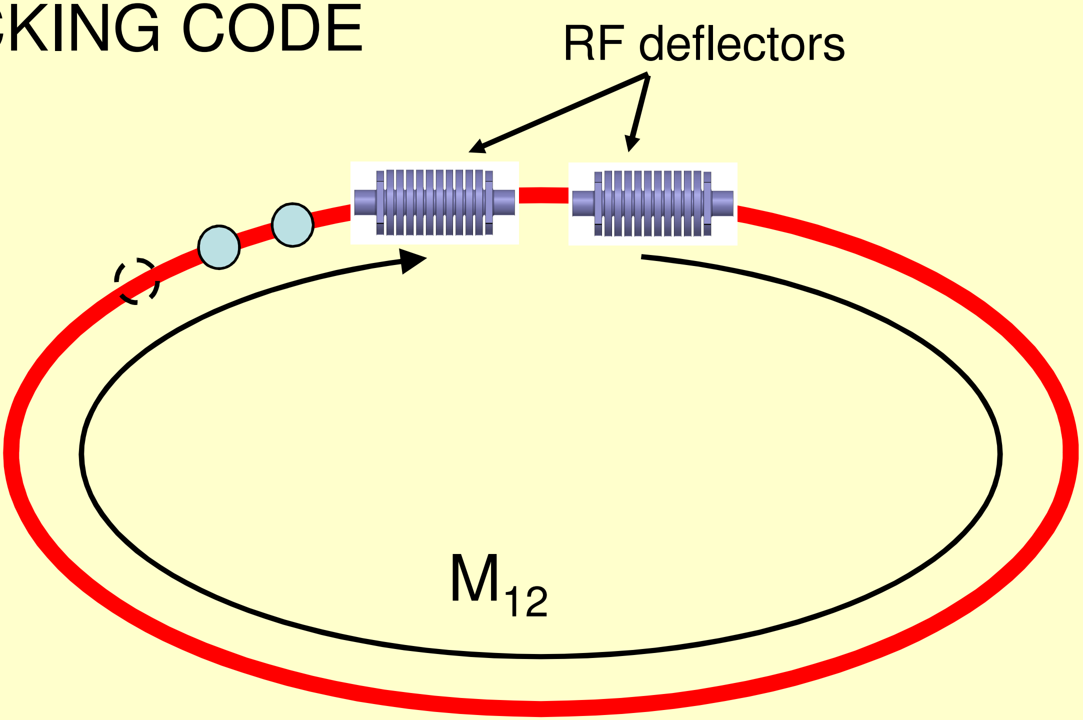
TRACKING CODE

A dedicated tracking code has been written to study the multi-bunch multi- turn effects.

All the ***results*** in term of the oscillation amplitude are ***proportional*** to:

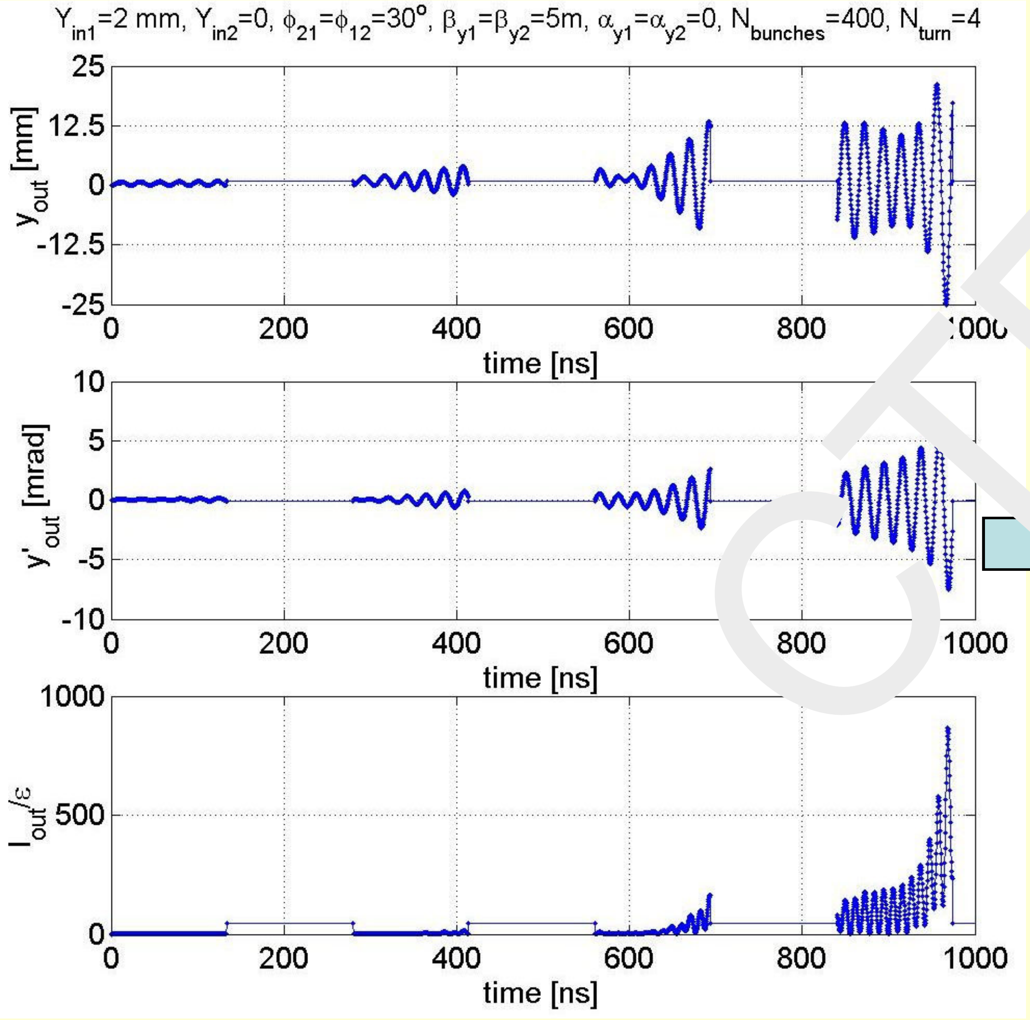
-the ***beam off axis*** ⇒ **<u>y=2 mm</u>** orbit in the deflector has been considered.

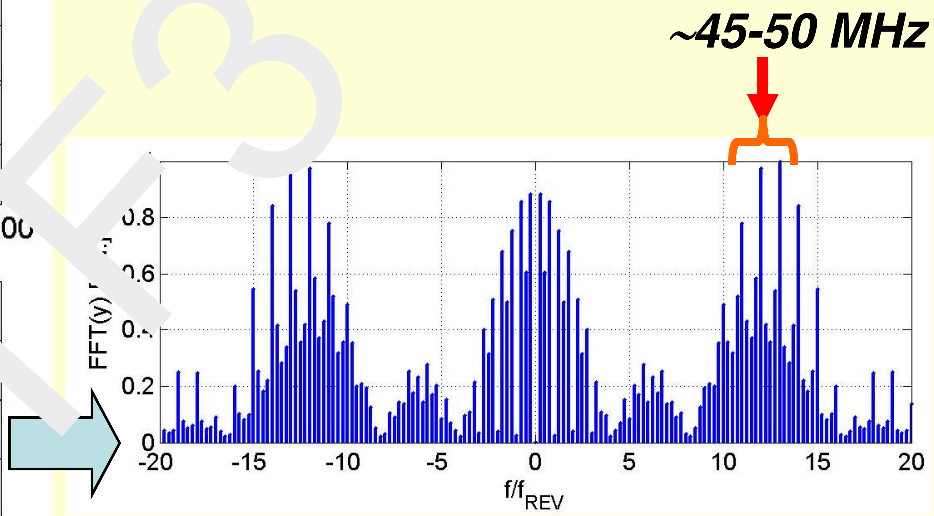
-the ***bunch charge*** ⇒ **<u>q=2.33 nC</u>** bunch charge has been considered



TRACKING CODE RESULTS

-The tracking allows studying the ***distribution of the Courant-Snyder invariants (I_{out})*** for all bunches and its dependence on the resonant mode properties and ring optical functions.

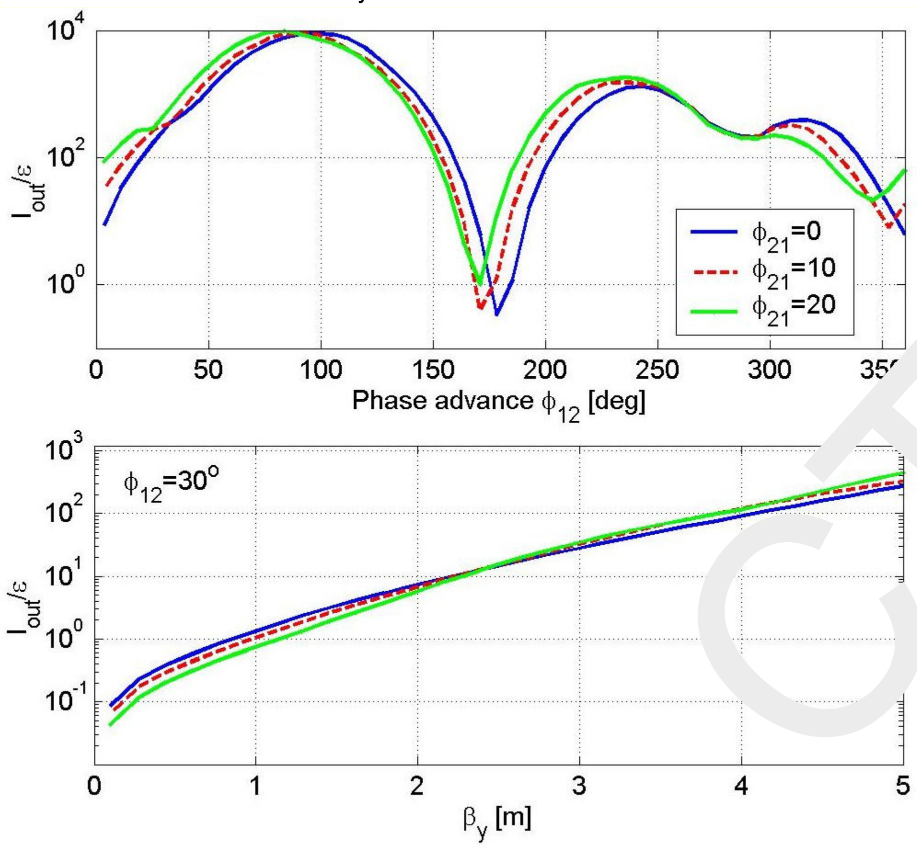




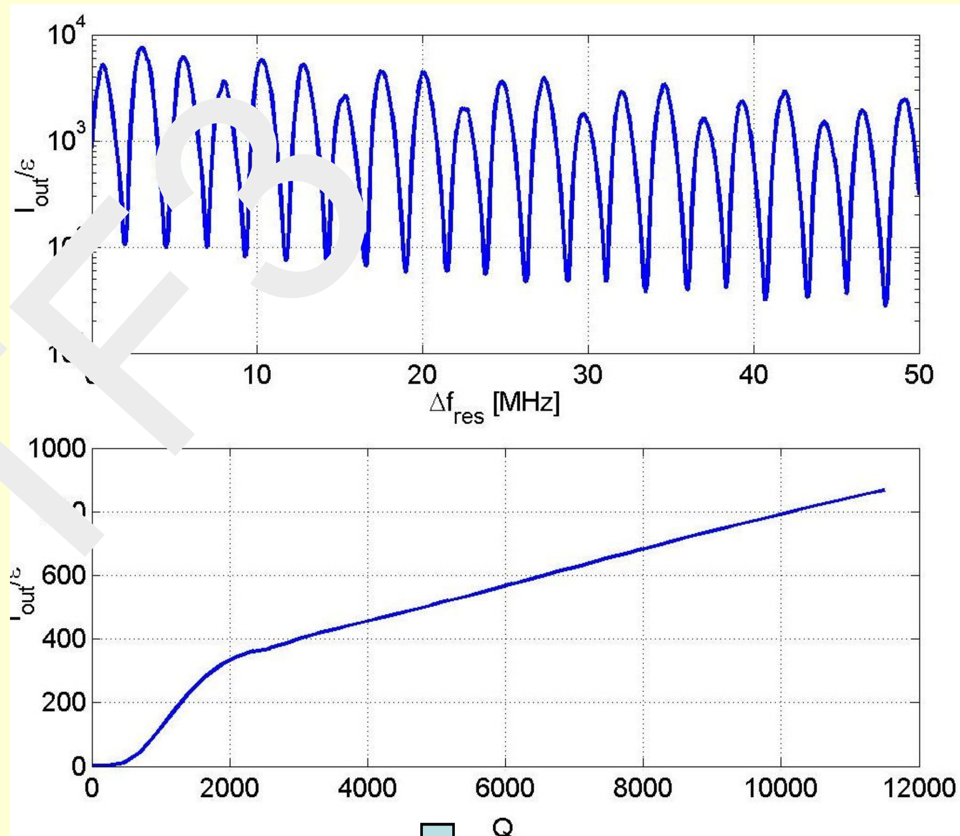
Simulations done for CTF3
Lower energy (100MeV)
lower current (15 A)

TRACKING CODE RESULTS: key parameters to reduce the instability

Optical phase advance between deflectors (ϕ_{12}) and β_y at the deflectors



Res. frequency and vertical mode quality factor dependence



They suggested ***to strongly shift the resonant frequencies*** of the vertical modes and ***to strongly reduce their quality factors***.

Choice of ring tunes and phase advances

- Rf deflectors loading : Qx far from integer, Qy near half integer
- Misalignment errors and beam loading: Qx, Qy far from integer

- In progress simulations for CLIC fms

(David will present them in CLIC workshop 09)

Conclusions

- FMS Layout and first order optics defined: two different possibilities for 1° ring
- 2° order chromaticity compensation in progress -> may require 1° order optics modifications, assured by system tunability
- Rf deflector main parameters defined
- Beam loading calculations in rf deflectors in progress-> may require rf deflectors parameters modifications